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Structure and micromorphology of glacial and non-glacial deposits in coastal bluffs at Sensala, Western Latvia

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Abstract The article reports results of structural and micromorphological investigation of heavily contorted sequence of glacial and non-glacial deposits. The main part of Pleistocene sequence comprises two units of different till facies, glaciofluvial, glaciolacustrine and marine deposits. The top of section was truncated by the glacial Baltic Ice Lake waters. This abrasion surface is marked by an occasional concentration of erratic boulders or boulder pavement, and covered by a thin layer of nearshore sediments, in places – by postglacial dune sand. The structure of Pleistocene deposits suggests multiphase glaciotectonic deformation including initial pro-glacial folding and faulting, following sub-glacial reshaping of preceding glaciotectonic structures and, finally, deposition of the upper till unit, and dêcollement. The OSL dating from the marine fine grained sand revealed that it was last bleached 43-45 thousand years ago, yielding to the Middle Weichselian age of the outcropped Pleistocene sequence.

Keywords *Glacial deposits, till fabric, glaciotectonics, deformation structures, OSL dating, micromorphology.*

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INTRODUCTION

The Quaternary geology of this territory has been subject to survey in the late 1960s in the course of 1:200,000 scale geological mapping, and in the first half of the 1980s in the course of 1:50,000 scale mapping. The renewed geological map in the scale of 1:200,000 was compiled without field observations (Juškevičs et al. 1998). Therefore, much of the information on Quaternary geology in this area is incomplete. On the other hand, the lack of detailed data hampers resolving the glacial history of the entire Western Latvia. Taking into account location of territory in the vicinity of Ventspils, erosion vulnerability of the coast and the diversity of landscapes, hopefully the results of this investigation could help in the coastal studies and spatial planning.

The objectives of the present study were to: (I) identify and recognize the genetic and lithological types of glacial and non-glacial deposits; (II) assess the extent of surface sediments and top of the underlying upper till unit at the mainland area adjacent to bluffs; (III) examine conditions of bedding and micromorphology; (IV) establish the regional ice-flow pattern of the study area; (IV) establish the OSL age of marine fine-grained sand.

STUDY AREA

The study area is located 10 km southwest of the city of Ventspils (Fig. 1A, B). It forms the northernmost stretch of the chain of the coastal bluffs that range with interruptions for a distance of almost 90 km in the central part of the Baltic Sea coast of Western Latvia. Up to 18 m high coastal bluffs at Sensala provide insight

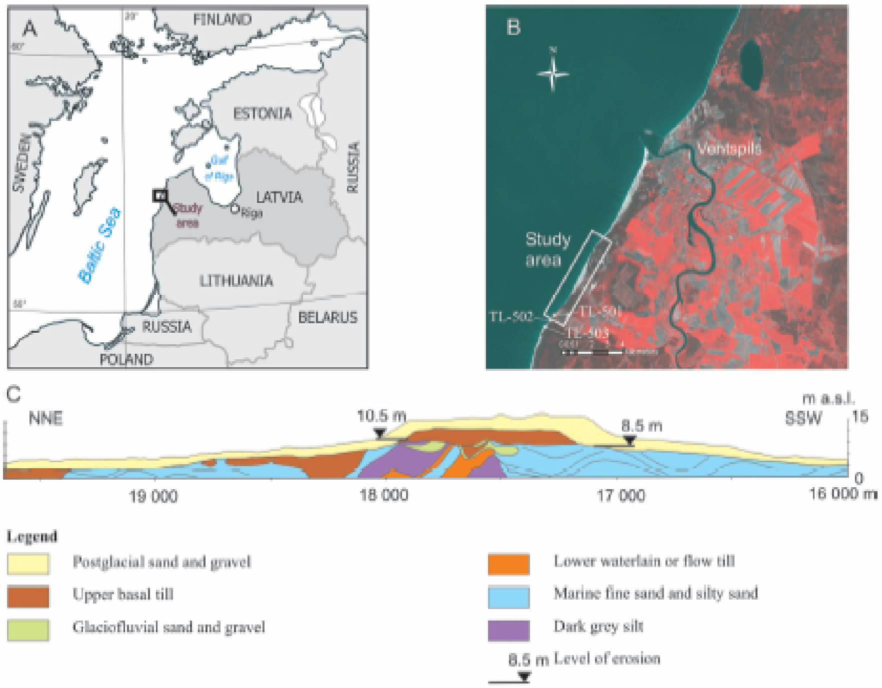

Fig. 1. Location of the study area and the generalized geological section of Quaternary deposits. A. A sketch map of the study area. B. A false-coloured satellite image showing the location of outcrops at Sensala (rectangle) and a contiguous area of the Coastal Lowlands altered mainly by the Baltic Ice Lake. White dots indicate the location of the OSL age dating sites, and TL-501, TL-502, TL 503 denote their reference numbers by Dating Laboratory, University of Helsinki. The satellite image is by courtesy of the Latvian Geospatial Information Agency. C. Generalized geological section. Meters at the horizontal distance of the section show the position of the outcrop N from the starting point of the profile by Dreimanis (1936).

Into Pleistocene glacial and non-glacial deposits for about a distance of 3.5 km (Fig. 1). The bluffs have been retreating by storm water erosion at an average rate of 0.8–1.5 m per year (Eberhards 2003), exposing the uppermost and more diverse part of the sequence of the Pleistocene deposits.

In a map view the outcrop is a cross section of the ridge that is linear and sub-parallel to ice flow direction. Based on structural geology of the ridge and its overall shape, it is suggested that this landform was formed as lateral moraine at the margin of the glacier tongue, and was successively overridden by the advancing glacier.

According to previous studies (Dreimanis 1936; Danilāns 1973; Meirons & Straume 1979; Juškevičs et al. 1998; Kalniņa 2001) the study area has been repeatedly overridden by Scandinavian ice sheets, at least from the Elsterian onwards. The recent landscape of the adjacent mainland area is very gently undulated sandy abrasion-accumulation plain of the Baltic Ice Lake altered to some extent by postglacial aeolian activity (Veinbergs 1964). The territory was an isle during Litorina Sea transgressions.

The study area is located on the north-eastern slope of the Baltic bedrock depression. The bedrock surface Ranges from 40 up to 60 m below sea level with regional inclination 3.3 m/km to WNW. According to the borehole data, the layered sequence of Middle Devonian dolomitic marl, clay, dolomite, gypsum and breccia are overlaid by a more than 60 m thick cover of Quaternary glacigenic, glaciofluvial, glaciolacustrine, lacustrine and marine deposits (Meirons & Straume 1979; Juškevičs et al. 1998).

So far stratigraphy, glacial sedimentology and structures of the Sensala section have not been investigated in detail. Glacial stratigraphy was based only on formal principles such as the correlation of till units between boreholes, differences in till colour or in petrographical and mineral composition (Konshin et al. 1970; Ulsts & Majore 1964; Danilāns 1973; Meirons & Straume 1979; Segliņš 1987; Kalniņa 2001). In the nearshore area, where according to the data derived from interpretation of seismic sequences, the thickness of the upper till Unit reaches up to 40 m, it was speculatively separated as distinct till units of the Saalian and Weichselian ages irrespective of the evident absence of inter-till deposits (Juškevičs et al. 1998, geological sections to map of Quaternary deposits). The upper till unit, which outcrops widely alongside the Baltic Sea coast, has already been referred to as of the Saalian age by Dreimanis (1936), later by Konshin et al. (1970), and Danilāns (1973). Konshin et al. (ibid.) stated that the non-glacial sequence underlying the upper till could be distinguished as "marine inter-till deposits" and were deposited before the penultimate glaciation. Danilāns (1973) proposed to distinguish these "inter-till marine deposits" as the Ulmale series. According to him, this sequence could be correlated to the Pulvernieki (Holsteinian) interglacial sediments (Danilāns 1973). On the basis of diatoms analysis Charamisinava (1971), later Meirons and Straume (1979) doubted Danilāns's stratigraphical interpretation. Deposits older than Holsteinian ones have been reported to be found to a limited extent (Danilāns 1973; Segliņš 1987), and are mostly restricted to the areas of glacial tunnel valleys and palaeo-incisions (Segliņš 1987).

Gaigalas et al. (1967) attempted to establish a regional glacial movement direction pattern for the eastern Baltic coastal area. They emphasized that during the last glacial maximum, the glacier advanced from the NNW direction out of the Baltic depression. Palaeo-glaciological reconstruction of the Scandinavian ice sheet dynamics through the Weichselian glacial cycle supports such a conclusion (Punkari 1997; Boulton et al. 2001). Besides the study area was located in the interaction zone of the Venta glacier tongue of the Usma ice lobe and the Apriķi glacier tongue (Zelčs & Markots 2004; Fig. 2).

MATERIAL AND METHODS

The Quaternary deposits composing the bluffs were mapped at a scale of 1:100. At nearly 500 meters long bluff section the structural geology as well as sedimentology, micromorphology and stratigraphic position of Pleistocene deposits and glacier dynamics were studied in detail (Fig. 2). Planar as well as linear elements of the glaciotectonic structures and till macro-fabric were measured in the field. The till and inter-till deposits were sampled for standard lithological and micro-morphological analyses.

Three samples of the basin fine-grained sand were taken from the section studied in detail for the OSL dating (Fig. 1). The samples were measured using single-aliquot regeneration (SAR) OSL method with quartz (Murray & Wintle 2000) at the Dating Laboratory of the Helsinki University.

Quaternary deposits were mapped using soil auger (AMS SIG MUD AUGER 4 IN) in the contiguous mainland. In order to achieve a general perception of the top of the upper till unit 20 boreholes were made. The topography of the area was derived from topographic maps of scale 1:10,000, and a three dimensional digital model of the terrain was developed.

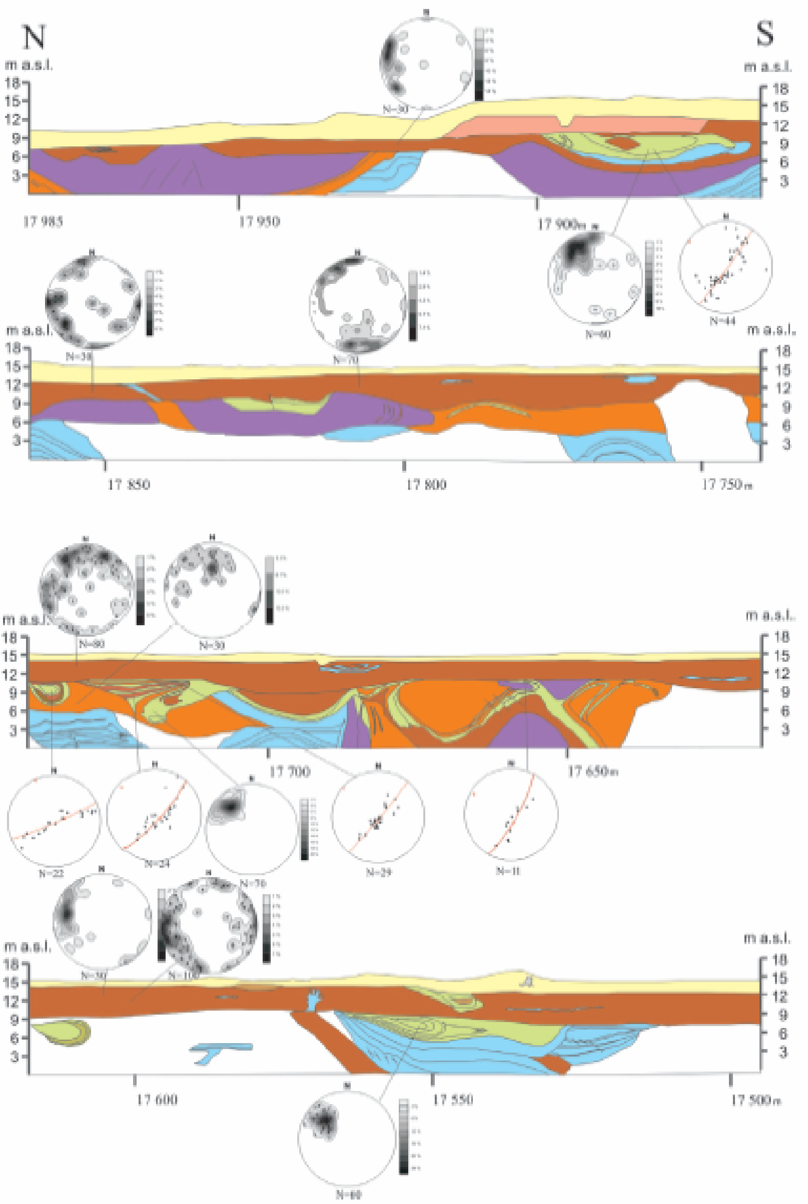

Fig. 2. The main section of Quaternary deposits studied in detail. Legend for deposits is as in Fig. 1. The diagrams with calculated contours are for till macrofabric measurements and point diagrams with calculated griddle represent spatial characteristics of planar elements such as foliation or bedding planes. N denotes number of measurements in each site. Solid lines at diagrams indicate the location of each measurement site. Meters at the horizontal distance of the section show the position of the outcrop N from the starting point of the profile by Dreimanis (1936).

Samples for thin-section preparation were taken using a metal container. The container was pushed into the deposits of the outcrop in a manner similar to that used by van der Meer (1996). The samples of well-consolidated diamicton were taken as single blocks. The upper face and northern direction were marked on each sample. In the laboratory the samples were air-dried and pre-impregnated with epoxy resin dissolved in acetone (in proportion 1:7) and after hardening cut into sections. In the second stage of cementation, the samples were impregnated with epoxy resin dissolved in acetone in proportion respectively 1:3. After impregnation thin sections were prepared in a manner similar to the procedure described by Camuti and McGuire (1999), and Carr and Lee (1998). The samples were cut and hand-ground in three stages. At the last stage corundum grinding powder of around Grit P2500 was used. Ground samples were mounted on glass slides, and after cutting of bulk material, all three grinding stages were repeated to reach the slide thickness of

20 μm, as indicated by the pale yellow interference colour of quartz grains. Three mutually perpendicular thin sections were prepared from each sample in all cases where it was possible.

Thin sections were examined using ore microscope MBS-10 and polarized light mineralogical microscope MIN-8. Recommendations for thin section examination of van der Meer (1993, 1996, 1997), Hart and Rose (2001) were followed. Morphological structures were observed and interpreted. The classification of micro-scale features of glacial sediment thin sections recommended by Menzies (2000), and Menzies and Zaniewski (2003) were used.

Micro-fabric investigations were performed on digital images with a resolution of 2400 dpi. The long axes of apparently elongated skeleton grains were digitally marked in CorelDraw graphical utility afterwards, vector data were exported to the mathematical spreadsheet program Microsoft Excel and directions of long axes were calculated. Data were graphically presented with StereoNet for Windows 3.03.

RESULTS

Litofacies

At the outcrop the Quaternary sequence comprises up to six distinct litho-facies (Fig. 2): dark-greenish grey silt, pinkish grey-fine grained sand with silt inter-beds, contorted lenses of sand and gravel, lower and upper till units, and a continuous layer of sand and gravel. In total, different kinds of glacioaquatic and marine deposits are present, as well as two different till units that were encountered at the outcrop.

Dark-greenish grey silt. Dark-greenish grey massive silt composes diapirs and partially overthrusted slabs. On the faulting planes silt has been mixed with diamicton indicating that after their formation diapiric structures have been reshaped and sheared beneath the glacier sole. The silt has a breccia-like micro-scale structure with angular to sub-rounded dark silt domains resting in a lighter colour matrix (Fig. 3). Most probably the brecciated structure was created during formation of the diapir, as the silt material has to be near the liquid phase during the sediment flow.

Elevation data calculated from boreholes testify that the top of the silt material is placed about 15-20 m higher at the central part of the bluff section and contiguous mainland than in the rest of the study area. Accordingly, it might be concluded that diapiric structures have been lifted with the amplitude of at least up to 20 m. The distance between cores of diapiric folds varies from 50 to 350 m.

Fine-grained sand. Pinkish grey fine-grained sand is commonly present in the lowest part of the outcrop, particularly on either side of the complexly deformed and dark-greenish grey silt cored diapir at the central part of the section (Fig. 2). The sediment sequence has a rhythmic structure with up to 1-m thick fine-grained sandy layers interbedded by approximately 20 cm thick silty material. Occasionally also brownish clay inter-beds are found in the sand strata. In some layers

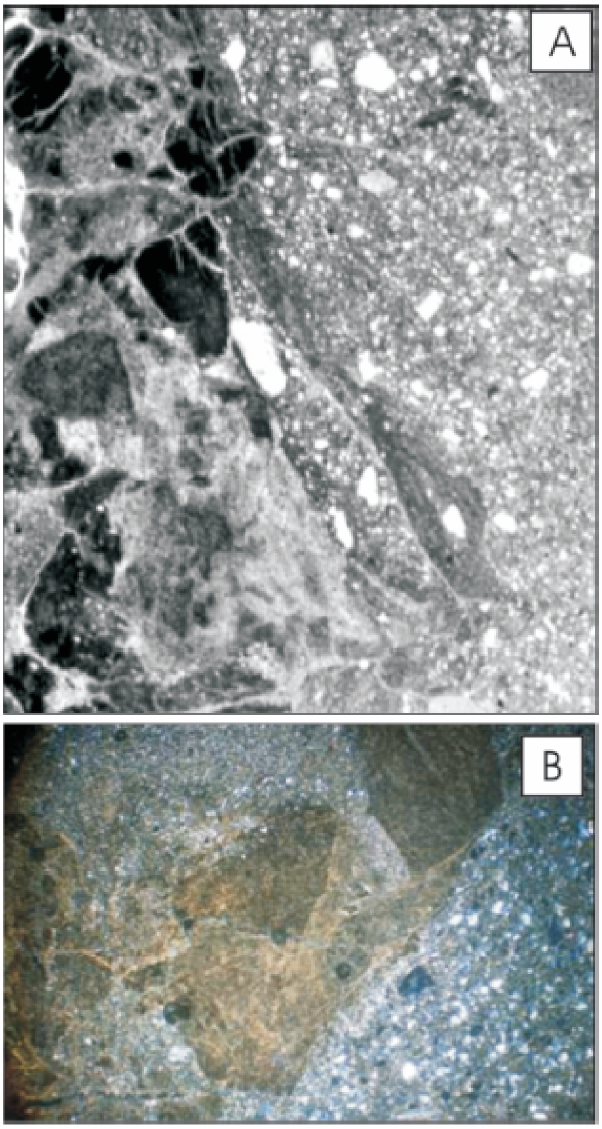

Fig. 3. Micro-morphological patterns of dark greenish grey silt material. A. Part of thin-section No. 088-1 showing brecciated structure of silt resting in the lighter matrix (left part of the picture). Shear zone cuts through the sediment on the contact between silt breccia and diamicton. The distinct lineation of the sand particles is visible in or near the shear zone. The lineation of elongated sand grains of diamicton has a broad maximum parallel to the silt and diamicton contact plane. Although close to the contact the lineation forms about 30° angle with it. There is rhombosepic plasmic fabric (by Menzies 2000) in some silt domains near the contact surface with diamicton (Fig. 3B). Probably plasma structure as well as micro-linearity formed like Riedel shears next to the distinct shear zone at the contact of silt and diamicton. The picture is approximately 7 mm wide.
B. Rombosepic plasma fabric (by Menzies 2000) in silt breccia. A grain on the silt and diamicton contact (indicated by arrow), probably such a fabric formed due to lateral stress generated by shearing on the boundary of the silt and diamicton. In polarized light; the picture is approximately 4 mm wide.

Wave current ripples, liquidification and water escape structures are common. Commonly fine-grained sand is deformed into 20 to 40 m long and up to a few m high gentle folds. Sand wedge structures were found cutting through glaciotectonic structures. According to French and Guglielmin (2000) such structures indicate that the sediment surface has been exposed to a cold and dry non-glacial environment. According to OSL dates, sedimentation of the fine grained sands occurred around 40 ka BP. The OSL age for samples TL 501, TL 502 and TL 503 was determined as 43±5.0 ka, 45±7.7 ka and 44±10 ka accordingly (personal communication with Dr. H. Jungner and Dr. K. O. Eskola). A similar age of fine-grained sand was obtained in three other places 20 to 40 km S, SW of the Sensala site (Dreimanis et al. 2004).

Contorted lenses of sand and gravel. Up to 20 m long and 5 m thick patches of intensively folded and distorted sand and gravel were encountered southerly from a mark of 17,900 m (Fig. 2). In most cases this unit overlaps both above-considered lithofacies, and was formed as a small delta-like feature in front of the advancing glacier.

Lower till unit. The lower till unit has a complex structure consisting of two parts. In the lowermost part this unit is mainly represented by sandy diamicton interpreted as facies of waterlain and flow till. Between 17.720 and 17.760 m waterlain and flow till are progressively replaced by diamicton that might be classified as basal till. At 17.575 and 15.525 m slabs of the basal till form two dyke-like bodies (Fig. 2). Pieces of the lower till are also observed below the silt slab (Fig. 2). Drag casts and folds and several tens of centimetres thick layers of very silty diamicton are observed on the contact of silt and diamicton revealing that the silt slab was dragged over the lower till. In places the uppermost part of the lower basal till has a markedly banded structure, with distinct evidence of glaciotectonic influence (Fig. 4A). Drag folds and boudinage structures are observed along with other minor shear zone structures. In micro-scale diamicton bands form boudin-like structures resting in a matrix of fine-grained sand and silt (Fig. 4B). It attests that diamicton was well consolidated and acted as a more competent material in comparison with more fluid (plastic) sand when banded till was formed due to shearing. Therefore it is more likely that till was sheared after deposition rather than during the deposition of it.

Upper till unit. The upper till unit is up to 4 m thick, a continuous dark olive-grey diamicton – interpreted as basal till. Occasionally several metres long and a few millimetres to several centimetres thick sand or silt intercalations can be observed in this till unit. In micro-scale these bands have step-like or undulating (Fig. 5) features. Less than 1cm long zones of distinct micro-lineation can be observed in thin-sections of upper till. Dip directions of step-like structures occasionally coincide with dip direction of zones of distinct micro-lineation. Most likely these structures have formed as local shear bands or so-called Riedel shears (Riedel 1929). The upper surface of the same silt band is mixed with diamicton, suggesting plastic deformation and associated rotation due to shearing. Deformation of the till layer implies active glacier movement after deposition of the till. Whether these deformations are local phenomena or indicate repeated glacier advance is uncertain. The mapping of the elevation of the upper till surface in the vicinity of the outcrop revealed a 500 m vide and almost 4 m high ridge stretching from W to E (Fig. 6). The ridge stretches perpendicular to the main stress direction as shown by a glaciotectonic structure analysis at the outcrop. The outcrop itself intersects the ridge approximately under an 80-100° angle. The most pronounced deformation with the deepest dêcollement surface is in the northern side of the outcrop. Commonly the dêcollement line gradually rises in the southern direction (Fig. 2). The maximum thickness of till also occurs along the deepest deformation layer.

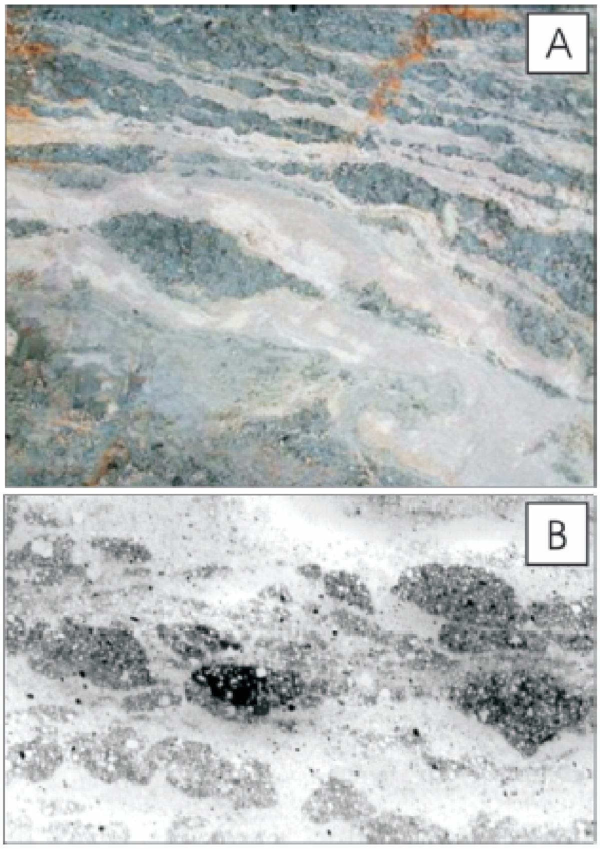

Fig. 4. Structural features of the banded till. A. Banded till and lens-like boudinage structure in the sandy layer in the outcrop at 17,725 m. The scene is 25 cm wide. It can be seen from the figure that the weaker sandy matrix underwent plastic deformation while diamicton experienced mixed – brittle and ductile strain. B. Photograph of thin section No. 054 showing a fragment of banded till. The picture is 2 cm wide. During shearing diamicton has been disintegrated and subsequently its clasts have been rounded by rotation. It might be concluded that disperse distribution of the matrix indicates high water pressure during shearing.

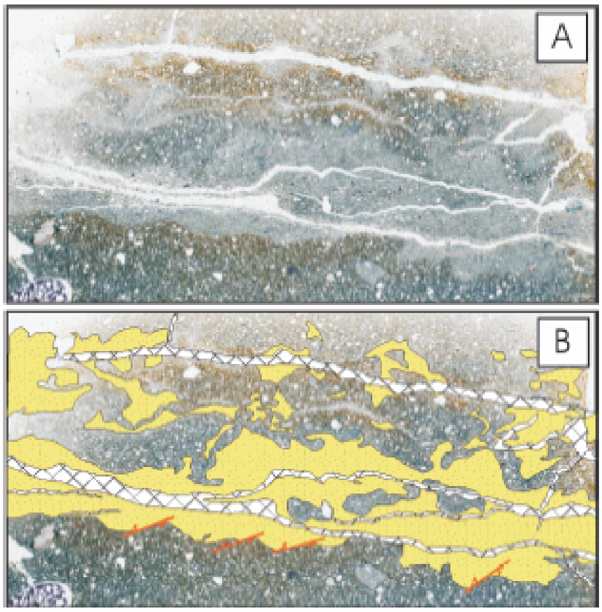

Fig. 5. The photograph (A) and interpretation (B) of thin section No. 072-1 showing a fine sand band in the upper till. Pictures are ~ 3 cm wide. In the lower picture the diamicton is marked by grey colour, and the sand bands are mapped as a dotted yellow attribute. On the lower boundary of the sand band distinct microfaults might be traced and interpreted as Riedel shears but all of the sand band – as a part of the shear band.

Continuous layer of sand and gravel. The continuous layer of sand and gravel or fine sand lies at the top of the outcrop. This layer comprises a thin layer of nearshore sediments and in some places is covered by postglacial dune sand with buried soil horizons. In some places, boulder concentration and pavements are present at the base of nearshore sediments.

Glaciotectonic structures and till fabric

Glaciotectonic structures are widely exposed throughout the outcrop. A conventional relationship can be drawn between sediment composition, glaciotectonic structures and their position in the outcrop. Inter-till sediments are deformed into stretched folds, while glaciofluvial sands and gravels are strained into augen-like structures (Fig. 7), but diamicton is mostly incorporated into stretched recumbent folds. Sandy marine sediments are positioned at the base of the outcrop, and therefore are less deformed and form nearly upright long and low folds (Fig. 2). Silt sediments are found in several slabs reaching in size some 20 m in width and approximately 5 m in height. The nature of the silt slabs suggests that their formation as diapir structures have been subsequently overridden. In the upper part the slabs comprise diamicton with a high content of silt. It could have formed during thrusting and deformation of the silt sediments. The breccia-like inner structure of the silt (Fig. 3A) indicates liquidification of the silt during diapirism.

It is supposed that diapir structures were formed at the glacier margin, where the largest pore water gradients could exist. Silt sediments are the most impermeable material in the sequence, and are most susceptible for viscous flow under high water pressure conditions, while sandy sediments are most likely to be able to drain rising water level through it. Hindmarsh (1997) has suggested that diapir formation could occur in a glacier marginal zone in loose, unfrozen sediments Supposedly, the formation of silt diapirs occurred at the glacial margin, when the largest pore water supply

Fig. 6. Topography of a top surface of the upper till unit as it is interpreted from borehole data. Vertical exaggeration is 100 times. Dotted line indicates the crest of the ridge. The crest of this ridge is parallel to the regional ice flow direction.

Fig. 7. Overturned asymmetrical fold below the upper till. The fold is composed of sand and gravel and cored by diamicton. Underneath the folded sand and gravel sediments is diapiric structure, which has been reshaped and sheared. The fold hinge is oriented from NW to SE, indicating local stress direction from NE (see Fig. 2 for location at 17,720 m of the section).

and pressure differences as well as a large gradient of glaciostatic pressure existed.

The axis of fold structures are oriented predominately in the NW-SE direction, suggesting the glacial stress direction, NE–SW (Fig. 2). In the central part of the folds the fabric of the deformed sand and gravel deposits is parallel to the fold axis. The dêcollement line of dynamic structures rises from NE to SW, suggesting a decrease of glacial stress to SW. The stretched nature of folds and the presence of augen-like structures indicate that folding was due to the drag of a moving glacier rather than lateral stress. Therefore it can be concluded that fold orientation is represents the local direction of the ice movement.

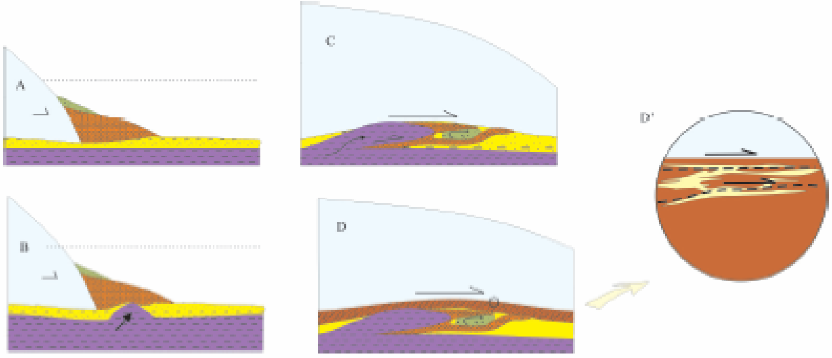

Fig. 9. Succession of the main glacial events at the Sensala site. A. Glaciofluvial and lacustrine sediments, along with waterlain till are deposited. B. Diapirs are formed in front of the advancing glacier. C. Sediments and diapiric structures are overridden and glaciotectonically deformed by the glacier. D. As the glacier continues to flow it becomes decoupled from the base deposits, and a shear zone is formed at or near the base of the glacier ice (D'). Legend – as in Fig. 1.

Measurements of till macro-fabric show relatively low statistical values. Predominant maxima of the pebble longitudinal axes show N, NE, S, SW directions of glacial stress (Fig. 2).

DISCUSSION

Structural geology of the ridge and its asymmetrical composition suggest unidirectional stress component directed perpendicular to the ice movement. At first sight, the directions of some macrofabric maxima listed the aforesaid appear to be contradicted with glacial stress direction derived from glaciotectonic structures. However it could be explained by re-orientation of till fabric during subsequent deformation. In general, these maxima correspond quite well to the established regional ice movement direction (Gaigalas et al. 1967; Boulton et al. 2001).

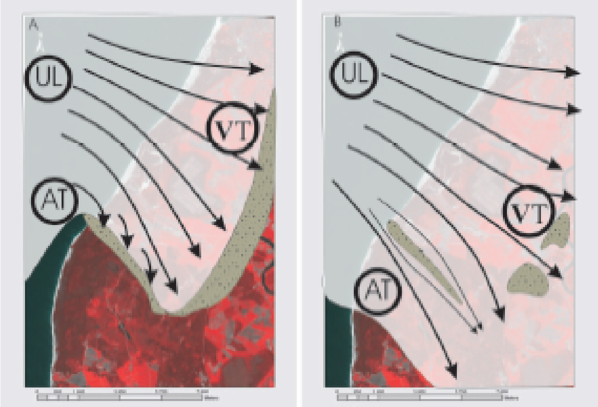

Fig. 8. Possible ice flow line pattern during formation of concealed ridge. A. The creation of the diapiric structures and formation of the lateral ridge. B. The continuous deposition of the till sequence and subglacial deformation and reshaping created as far as glaciotectonic structures. AT – Apriķi glacial tongue of Kursian ice lobe; UL – Usma ice lobe; VT – Venta glacial tongue.

Structures in the outcrop indicate mostly shearing and thrusting of the substratum, leading to minor thrust structures in silt domes, and drag folds and augen structures in coarser material. Conditions which caused offset of the main stress direction could exist on the margin of the advancing outlet glacier tongue, similar to those that form lateral moraines in modern glaciers. As the glacier kept advancing, the material was squeezed out and pushed of the sub-sole in the lateral direction. Soft deformable glacier bed rheology seems to play a major role in the evolution of deformation structures, and it was deforming near the glacier edge just by the pressure load of the glacier to the side of the lateral moraine created by the particular ice flow. In such a case also a temporary moraine possibly could form in front of the glacier, but it would be removed as the glacier continues to advance.

Figs. 8 and 9 show hypothetical glacier advance patterns during the formation and partial overriding of the ridge. In the feed region of the ice stream the movement pattern would be convergent, on the contrary – in the ablation region the movement pattern would be divergent (Punkari 1997). In this case it could be noted that the movement pattern is divergent, such as the observed structures formed in the ablation sector of the potential ice stream (ibid).

The sequence of inter-till marine sediments in western Latvia have been for a long while considered as the late Holsteinian or the early Saalian deposits (Danilāns 1973; Konshin et al. 1970). However new OSL dates of fine-grained sandy sediments indicate that at least, the upper part of the sequence is much younger, i.e. Middle Weichselian. As mentioned below, several other yet unpublished OSL data from this region of sandy sediments suggest a similar age or even a little younger age (Dreimanis et al. 2004, personal communication with Dr. H. Jungner and Dr. K. Eskola). Sampling sites for these data are apart from each other at a distance from 5 up to 20 km. Therefore it is suggested that a large proglacial basin existed during the Middle Weichselian before 40-45 ka BP. The thick bands of sandy sediments suggest fast sedimentation in this basin. The presence of laminated diamicton patches, that cover sandy sediments without observable hiatus, could indicate that the latest phase of sedimentation occurred in the immediate vicinity of the glacial margin.

The dark-grey silt might be referred to as of Late Eemian – Early Weichselian age, which is partly supported by finds of diatom fauna by Charamisinava (1971) in the similar sediments in the borehole approximately 100 km south of the Sensala site suggesting there Weichselian age. Also biostratigraphical investigations of similar sediments south of Sensala suggest marine sedimentation of silt during Eemian interglacial cycle (Kalniņa et al. 2000).

From structural geology point of view there can be distinguished three main structural formation stages in the outcrop (Figs. 8, 9): (I) the creation of the diapiric structures, (II) the formation of the lateral ridge and continuous deposition of the till sequence, (III) the subglacial deformation and reshaping created as far as glaciotectonic structures with final occurrence of minor water escape structures.

CONCLUSIONS

During deglaciation, which occurred in Western Latvia between 16.5 and 12 ka BP, large Baltic ice stream splits in to several ice lobes that terminate in smaller glacier tongues (Fig. 8). The advance of these tongues in the first phases occurred through several ice flows, which protruded into the terrain, and deformed the soft glacier bed, forming frontal diapiric structures and a lateral moraine ridge. Evidently, the Sensala outcrop reflects the remains of such an ice marginal formation like a lateral moraine. During glacier propagation all frontal topographic features were removed, but the radial patterns as lateral moraines could be partly preserved.

Glacier dynamics in the area have been mostly controlled by glacier bed rheology, which resulted in an assemblage of specific glacier landforms and glaciotectonic features: overridden, partly preserved lateral moraine lineation and its unidirectional stress pattern, and diapiric structures formed at the glacier margin. From the outcrop studies it can be concluded that since the glacier started to advance it became soon decoupled from the glacier bed, and the shear zone developed near the glacier bed. The upper till wa deposited continuously, but the glacier was still active also after deposition of the till as in several places a comparatively thicker shear zone was developed in the till layer.

Contrary to former expectations, the pre-Holocene deposits outcropped at Sensala, correspond to the Middle Weichselian and the Late Weichselian age. The confirmation of this conclusion the OSL dates of the basin sandy sediments underlying the Upper Weichselian till can serve as a good proposition for further investigations to re-interpret the stratigraphical position of the dark olive-grey till throughout Western Latvia.

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